

Cool Stars in Hot Places
ASP Conference Series, Vol. To appear in proceedings of Cool Stars 14,
Ed. Gerard Van Belle

Cool Stars in Hot Places

S. T. Megeath

*Ritter Observatory, Department of Physics and Astronomy, University
of Toledo, Toledo, OH 43606*

E. Gaidos

*Department of Geology & Geophysics, University of Hawaii, Honolulu,
HI 96822*

J. J. Hester

*Arizona State University, Department of Physics & Astronomy, Tempe,
AZ 85287*

F. C. Adams

Physics Department, University of Michigan, Ann Arbor, MI 48109

J. Bally

*Center for Astrophysics and Space Astronomy, University of Colorado,
Boulder, CO 80309*

J.-E. Lee

*Physics and Astronomy Department, The University of California at
Los Angeles, Los Angeles, CA 90095*

S. Wolk

Harvard Smithsonian Center for Astrophysics, Cambridge, MA 02138

Abstract.

During the last three decades, evidence has mounted that star and planet formation is not an isolated process, but is influenced by current and previous generations of stars. Although cool stars form in a range of environments, from isolated globules to rich embedded clusters, the influences of other stars on cool star and planet formation may be most significant in embedded clusters, where hundreds to thousands of cool stars form in close proximity to OB stars. At the cool stars 14 meeting, a splinter session was convened to discuss the role of environment in the formation of cool stars and planetary systems; with an emphasis on the “hot” environment found in rich clusters. We review here the basic results, ideas and questions presented at the session. We have organized this contribution into five basic questions: what is the typical environment of cool star formation, what role do hot star play in cool star formation, what role does environment play in planet formation, what is the role of hot star winds and supernovae, and what was the formation environment of the Sun? The intention is to review progress made in addressing each question, and to underscore areas of agreement and contention.

1. What is the Typical Environment of Cool Star Formation?

Cool stars form in a range of environments, from isolated Bok globules, to modest sized clusters containing 100-200 stars, and finally to large, dense clusters with thousands of cool stars and several to tens of OB stars. This is in sharp contrast to OB stars, which form almost entirely in large clusters. This motivates the question: in what environment do most cool stars form?

Surveys of the molecular gas in our Galaxy indicate that most of the cold molecular gas is in giant molecular clouds (GMCs) with masses of 10^5 to $10^6 M_\odot$ (Heyer & Terebey 1998). These massive molecular clouds are thought to form entire associations of hot OB stars as well thousands of low mass stars. Coupled with analyses indicating that 80-90% of cool stars form in large clusters (Porras 2003; Lada & Lada 2003; Carpenter 2000); these results seemed to point to a galaxy in which the vast majority of cool star formation takes place in rich crowded clusters in close proximity to hot stars. However, since there was little information on the numbers of isolated stars, the analyses of Porras (2003) and Lada & Lada (2003) considered only stars in groups and clusters. In an analysis of the 2MASS point source catalog toward several molecular clouds, Carpenter (2000) found evidence for substantial numbers of isolated stars, but the estimates contained significant uncertainties.

More recently, surveys of giant molecular clouds with the *Spitzer* space telescope provided the means to identify isolated young stars and protostars through the infrared excesses from their disks and envelopes (Allen et al. 2007). *Spitzer* surveys of four giant molecular clouds containing young massive hot stars, the Orion A cloud, Orion B cloud, Cep OB3 cloud and Mon R2 cloud, show that in addition to clusters associated with regions of massive star formation, there are large number of stars in small groups or isolation. In these clouds, 46% of the young stars with excesses are found in clusters with over 90 sources, 11% are found in small clusters of 90-30 stars, 8% in groups of 30-10 stars, and the remaining 35% in groups with less than 10 members or isolation (Megeath et al. 2007; Gutermuth et al. 2007). About 33% of the stars are found in the two largest clusters with over 700 members each. Thus, although most cool stars may form in OB associations, young cool stars in OB associations are not found primarily in large clusters. Instead, they are found in a range of environments, with a significant fraction of stars forming in relative isolation several to tens of parsecs away from the nearest OB stars (Fig. 1).

2. What Role do Hot Stars play in Cool Star Formation?

Although cool stars dominate star-forming regions in both number and total stellar mass, hot stars are thought to be the primary agents of molecular cloud evolution. The extreme-UV radiation from young O and early B-type stars photoionizes the surfaces of molecular clouds, resulting in flows of ionized gas which erode the clouds. Far-UV radiation may play a similar role in regions where only B-stars are present by heating and photodissociating the molecular gas. Clusters with O and/or B stars and ages of only a few million years appear to have partially or fully dispersed their molecular clouds. An example is the 2.5 Myr old σ Ori cluster (Sherry et al. 2004); this cluster sits *outside* the Orion B cloud

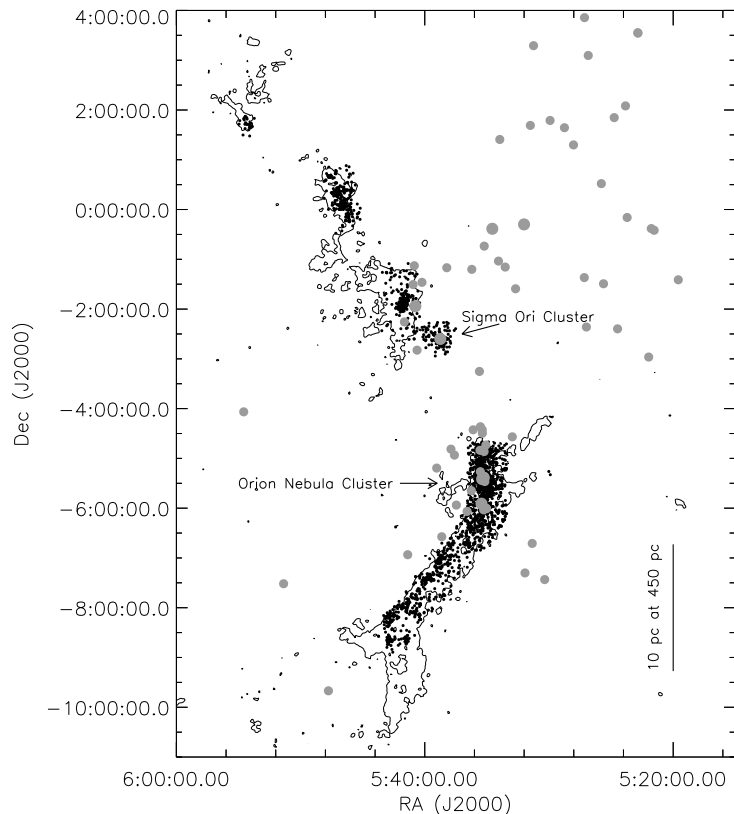


Figure 1. The Orion OB association. The contours show an A_V map of the Orion region made from the 2MASS database (Gutermuth, p. com.), the gray circles are the O stars (large circles) and B stars (small circles) from Brown et al. (1994) and the dots are *Spitzer* identified young cool stars and protostars (Megeath et al. 2007; Hernandez et al. 2007). Only regions of high molecular column density and the σ Ori cluster have been surveyed by *Spitzer*, and many more young cool stars certainly exist in the OB association

(Fig. 1). Other examples are discussed in Allen et al. (2007). It is estimated that only 10% of embedded clusters survive gas dispersal and persist as clusters for more than 10 Myr (Lada & Lada 2003).

The detection of Evaporating Gaseous Globules (EGGs), 1000 AU diameter photoevaporating dark globules, demonstrated that hot stars may directly impact protostellar evolution (Hester et al. 1996). EGGs appear to be protostellar or prestellar cores which emerge from their parental clouds as the surrounding lower density gas is ionized (Hester & Desch 2005). In M16, 15% of the EGGs contain embedded stars, indicating that they are the sites of recent or ongoing star formation (McCaughrean & Anderson 2002). This suggests that hot stars can directly affect protostellar evolution by photoevaporating the infalling gas

and limiting the ultimate mass of the nascent star. However, it is not known what fraction of stars emerge from their clouds in EGGs.

A more controversial issue is whether OB stars trigger cool star formation. This possibility has been discussed in the literature for decades (e.g. Elmegreen & Lada 1977). Hester & Desch (2005) proposed that in regions with hot stars, cool star formation is driven *primarily* by shock fronts preceeding advancing ionization fronts. The shock fronts overtake and compress pre-existing density enhancements, inducing collapse and the formation of clusters of low mass stars. Evidence for this is found in the detection of clusters of young stars at the surfaces of molecular faces being eroded by hot stars (Sugitani et al. 1995; Megeath et al. 2004; Allen et al. 2006). However, additional evidence, such as the detection of the shock fronts, is needed to determine whether the clusters have been triggered, or whether they are regions of ongoing star formation which have been overtaken by ionization fronts (Megeath & Wilson 1997).

Although there is growing evidence that triggering does happen, it is not clear what fraction of cool star formation is triggered. Assessing the overall importance of triggered star formation can be difficult due to the rapid evolution and even rapid motions of OB stars. For example, Hoogerwerf et al. (2001) argued that the interaction of the ι Ori binary system with a second system led to the ejection of the runaway stars AE Aur and μ Col 2.5 Myr ago (both are O9.5 stars). Although they suggested that these stars originated in the Orion Nebula Cluster, the lack of a visible HII region surrounding ι Or, an O9 III star which in projection appears coincident with the Orion A cloud, suggests that it is several to tens of parsecs away from the Orion A molecular cloud and is part of the 5 Myr OB1c association (Brown et al. 1994). At the time of their ejection, these three O-stars may have had a significant impact on the Orion A cloud, and could have been responsible for triggering star formation in the Orion Nebula Cluster. Another possible example is the LDN 1551 dark cloud in the Taurus dark cloud complex. This cloud has a cometary morphology with the “head” of the comet pointing toward the Orion constellation. Moriarty-Schieven et al. (2005) argued that the cometary shape may be due to the interaction of LDN 1551 (149 pc from the Sun) with the B8I star Rigel (Hipparcos distance is 240 pc) and the M2I star Betelgeuse (Hipparcos distance 130 pc). The high proper motion of Betelgeuse would place it southeast of LDN 1551 several million years ago; hence, both Betelgeuse and Rigel could have plausibly interacted with LDN 1551, creating the cometary morphology.

These observations demonstrate the difficulties in determining causal relationships between subsequent generations of star formation and establishing the importance of triggering. Although ongoing triggering can be identified by the detection of clusters near ionization fronts, in many cases, evidence of triggering may be erased by the evolution and motion of massive stars.

3. What Role does Environment Play in Planet Formation?

Environment may also play a role in planet formation by altering the properties of protoplanetary disks. We discuss here two mechanisms: tidal interactions between stars in clusters and the photo-ablation of disks by UV photons from nearby OB stars.

Tidal interactions occur when a disk around a star in a cluster is distorted or stripped during a close encounter with another cluster member. Such interactions appear to be unimportant. Adopting a stellar density of 10^4 pc^{-3} (the *peak* density for many embedded clusters) and assuming virialized velocities, Gutermuth et al. (2005) used a simple mean free path argument to estimate the frequency of close approaches. They estimated that even in the dense, central cores of clusters, close approaches at distances of 100 AU would occur once in a 10 Myr interval. However, the high stellar densities assumed by Gutermuth et al. may only persist for a few million years before the clusters begin to expand. This result is supported by N-body simulations of bound clusters which show that such interactions are rare over the lifetime of an embedded cluster (Adams et al. 2006; Throop & Bally in prep). Adams et al. (2006) find that each star in a 1000-member (initially) embedded cluster will experience one close-approach within 700-4000 AU over a 10 Myr interval. This distance is more than three times the typical radius of observed circumstellar disks in nearby dark clouds (Andrews et al. 2007) and much larger than the size of the Solar System. Since the adopted timescale for gas removal in these simulations was 5 Myr, longer than the observed timescale (Sec. 2), the close-approach distances should be considered lower limits. In summary, the results from three independent investigations are in agreement; unless embedded clusters exist in our galaxy with much higher stellar densities than observed in nearby regions such as the Orion Nebula Cluster, tidal interactions in clusters rarely influence disk evolution and planet formation.

In contrast, photoevaporation of disks by nearby OB stars appears to be a much more influential process. The UV radiation from the OB stars heats the gas in disks through photoionization and photodissociation, resulting in flows of gas off the disks. This process was discovered in VLA and HST observations of young stars in the Orion Nebula (Churchwell et al. 1987; O'Dell & Zheng 1994). The inferred mass loss rates were $10^{-7} M_{\odot}$, suggesting disk lifetimes of only a few hundred thousand years (Bally et al. 1998). However, the mass loss occurs in the outer disk where the thermal velocity of ionized gas exceeds the escape velocity from the star, and the gas in the inner disk may not be strongly affected. More recent calculations include the effect of the far-UV radiation and the time dependent nature of the UV-field as the stars orbit within the cluster potential. Adams et al. (2004) calculate the mass loss from a disk as a function of the intensity of the far-UV radiation field. They find the radiation field can truncate a disk to the size of our solar system in several million years; the exact radius depends on the duration of the exposure to UV radiation, the intensity of the UV radiation, and the mass of the central star (Adams et al. 2004). Throop & Bally (in prep) use N-body simulations to calculate the time dependent flux of UV radiation incident on a young star with disk as it orbits in a cluster which contains OB stars in its center. They find that typical stars experience only a brief exposure to intense UV as they pass within 10,000 AU of the central OB stars. Consequently, the UV flux incident on a disk varies in an stochastic manner over the lifetime of the cluster.

Recently, Throop & Bally (2005) proposed that the photoevaporation of disks may in fact trigger the formation of planets. In their model, grain growth and dust settling concentrates dust grains in the midplane of the disk. Consequently, the ablation of the gas from the disk surface (as well as the remaining

dust grains entrained in the gas) reduces the ratio of the gas surface density to dust surface density. If the surface density of gas is reduced to less than 10 times the dust density, the disk becomes unstable to gravitational collapse (Sekiya 1998; Youdin & Shu 2002).

Although photoevaporation may be important in rich embedded clusters with OB stars, many young cool stars in OB associations are not found in such clusters. Young cool stars with disks identified in the Spitzer survey of the Orion A cloud have a median projected distance of 4.1 pc to the nearest O to B0 star, and a median projected distance of 2.1 pc to the nearest B1-B3 stars (Megeath et al. 2007). Hence, in OB associations, most cool stars may form at large distances from the central OB stars and are unaffected by their UV radiation.

4. What is Role of Hot Star Winds and Supernovae?

Chandra X-ray observations of young stellar clusters have detected diffuse X-ray emission in nine regions. The total luminosities of this gas range from $1 - 200 \times 10^{33} \text{ erg s}^{-1}$ (Wolk et al. 2002; Townsley 2006). Although supernovae could generate this gas, in most cases the diffuse gas appears to be generated by stellar winds from massive stars colliding with other winds or the surrounding HII region. However, in the Carina region, a component of hot gas enriched in Fe was likely created by a supernova (Townsley 2006). The impact of the extremely hot gas on star and planet formation is not well understood. In addition to destroying the surrounding the cloud, the blast waves from a supernova could compress surrounding cores of gas causing them to collapse into stars (Boss 1995; Melioli et al. 2006). Disks can survive at distances of ≤ 1 pc from a supernova (Chevalier 2000); however, these disks will be heated by the radiation and blast wave, and may also be stripped by the blast wave when the disks are only 0.25 pc from the supernova (Chevalier 2000). The hot X-ray gas created by winds may fill bubbles within the larger HII region. This hot, low density gas would be transparent to UV photons, and hence any young stars within the bubble may be exposed to a more intense UV field than those in the surrounding HII region.

5. What Was the Formation Environment of the Sun?

Did our Sun also form in the “hot” environment of a large embedded cluster? Tremaine (1991) and Gaidos (1995) proposed that our Solar System might preserve dynamical evidence of its birth environment. Gaidos (1995) and Adams & Laughlin (2001) used the low inclination and eccentricity of Neptune to place constraints on the time-integrated tidal field of a cluster and the closest stellar passage. However, such reasoning must now be re-examined in light of the expectation that most embedded clusters expand and disperse in a few Myr (although some clusters would form bound open clusters, Sec. 2) and the realization that Neptune (and Uranus) migrated outward to its present orbit by scattering in a residual planetesimal disk, a process that was probably not completed until after a parental cluster dispersed (Hahn & Malhotra 2005). Scattering inside the disk itself, which dampens any non-circular motion, could have produced the low eccentricity and inclination observed today. Similar arguments can

be made that other parts of the outer Solar System (the Edgewood-Kuiper belt, Oort Cloud) formed after the cluster evaporated (Levison & Morbidelli 2003). Kenyon & Bromley (2004) and Morbidelli & Levison (2004) proposed that Sedna, a member of the scattered Kuiper Belt, was produced by the close passage of a star, but there are other explanations (Barucci et al. 2005; Gladman & Chan 2006). Thus, it is likely that the structure of the outer Solar System post-dates an embedded cluster phase.

The strongest evidence for an early cluster environment is the inferred presence of short-lived radionuclides (SLRs) during the formation of solids now found in meteorites. There are at least three possible sources of SLRs: particle irradiation within the primordial solar nebula, the wind from a nearby AGB star, and the wind and/or supernova ejecta from a nearby massive star. The discovery of ^{60}Fe in the early Solar System (Tachibana & Huss 2003) firmly establishes that the Sun formed in a rich cluster containing massive stars (Hester 2004; Hester & Desch 2005). Neutron-rich isotopes such as ^{60}Fe cannot be produced by particle irradiation. The uniform distribution of the SLR ^{26}Al makes it unlikely it was produced by irradiation (Thrane et al. 2006). Finally, it is statistically unlikely that the SLRs originated in an AGB star (Kastner & Myers 1994).

Further evidence is found in the mass-independent fractionation of the oxygen isotopes (^{17}O and ^{18}O) in meteorites. Following a proposal by Clayton, Grossman & Mayeda (1973), Lee et al. (2007) have made a theoretical analysis of the time-dependent chemistry in a collapsing envelope subjected to an external UV field. Due to “self-shielding” of the much more abundant C^{16}O , the UV field preferentially dissociates C^{18}O and C^{17}O , producing an enhancement of ^{18}O and ^{17}O in the gaseous envelope. These heavier isotopes are then incorporated (as water) into ice grains and transported into the inner region of the solar nebula. This process depends on the intensity of the external UV radiation field (from OB stars) so that the measured fractionation can constrain the formation environment of the Sun. Lee et al. (2007) conclude that the observed isotopic ratios are best explained by a radiation field 10^5 greater than the interstellar field, again supporting the presence of nearby massive stars.

The current evidence firmly indicates that the Sun formed in a hot environment enriched by the ejecta of one or more nearby supernova; however, there is a continuing debate over how the solar nebula was enriched. Cameron et al. (1995) argued that the enrichment occurred when the collapse of the proto-solar molecular cloud was triggered by the blast wave of a supernova (also see Vanhala & Boss 2002). Hester & Desch (2005) question whether this process could enrich the collapsing molecular gas. Alternatively, the protostellar envelope of the Sun may have been directly enriched while collapsing onto the proto-Sun (Looney et al. 2006). For example, if the solar system formed in an EGG, then it may have been subjected to a blast wave from a supernova. Finally, the SLRs may have been injected directly into the disk of the solar nebula when the Sun was in its T-Tauri phase; a possible mechanism for this is the “aerogel” model, in which grains in SN ejecta are decelerated and vaporized within the gaseous primordial disk (Ouellette et al. 2005). This scenario is supported by observations showing that 40% of disks may persist for 4 Myr (Hernandez 2007), the lifetime of a $60 M_{\odot}$ star.

Recent quantitative analyses have constrained the distance between the Sun and the supernova from which the SLRs presumably originated. If the enrichment occurred while the Sun was in a T Tauri phase with a 200 AU disk (Andrews et al. 2007), the estimated distance is between 0.04-0.4 pc (Looney et al. 2006; Ellinger et al. in prep). If the enrichment occurred in the protostellar phase (5000 AU diameter), the estimated distance is between 0.12- 1.6 pc (Looney et al. 2006). The question has been raised whether these distances are consistent with observations showing that embedded clusters largely disrupt their parental cloud and disperse in a few million years (see Sec. 2). The dispersal of the molecular gas makes the presence of nearby protostars unlikely, and the subsequent expansion of the cluster make the presence of young stars with disks less likely. There are possible solutions to this problem. The Sun may have remained close to a hot star as the cluster dispersed. Only one low mass star with a disk is found within a projected distance of ~ 0.3 pc of the O6 star HD206267 in the 4 Myr old IC 1396 association (Sicilia-Aguilar et al. 2006), suggesting that this may be rare occurrence. The Sun may have been a bound companion to a massive star, such as the companions with disks found around the OB stars comprising the Orion Trapezium (Schertl et al. 2003); however, it unclear how long such a disk may survive. The Sun could have formed in a massive embedded cluster which evolved into a bound open cluster. In this case, the solar system would have to survive photoevaporation and perturbations from tidal interactions as it orbited within the cluster (Adams & Laughlin 2001). Finally, the solar system may have been enriched by the combined ejecta of many supernova (Hester & Desch 2005; Williams & Gaidos in prep). Additional data on SLRs in meteorites, detailed modeling of the evolution and dispersal of embedded clusters, and the study of other planetary systems in hot environments should bring a more detailed understanding of our Sun's formation environment.

The presence of SLRs may have had a significant impact on planet formation in the solar nebula. Radioactive decay of ^{26}Al and ^{60}Fe provides by far the largest source of energy for melting and differentiating planetesimals in the early Solar System (Bizzarro et al. 2005; Hevey & Sanders 2006). In summary, it has been amply demonstrated by observation and theory that environment plays a significant role in the formation of cool stars and planets. A comprehensive understanding of star and planet formation must not treat young stars and protoplanetary solely as isolated objects, but as parts of larger associations and clusters in which the formation of cool and hot stars are inextricably linked.

References

- Adams, F. C., Hollenbach, D., Laughlin, G., Gorti, U. 2004 ApJ, 611, 360.
- Adams, F. C., Proszkow, E. M., Garuzzo, M., Myers, P. C. 2006 ApJ 641, 504.
- Adams, F. C., & Laughlin, G. 2001, Icarus 150, 151.
- Allen, L. E., Hora, J. L., Megeath, S. T., Deutsch, L. K., Fazio, G. G., Chavarria, L., Dell, R. W., 2005, IAU 227, eds. Cesaroni, R., Felli, M., Churchwell, E.
- Allen, L., Megeath, S. T., Gutermuth, R., Myers, P. C., Wolk, S., Adams, F. C., Muzerolle, J., Young, E. T., & Pipher J. R. 2007, Protostars and Planets V.
- Andrew, S. M., Williams, J. P. 2007 ApJ in press.
- Bally, J., Sutherland, R. S., Devine, D., & Johnstone, D. 1998, ApJ 116, 293.
- Barucci, M. A., Cruikshank, D. P., Dotto, E., et al., 2005 A&A 439, L1.
- Bizzarro, M., Baker, J. A., Haack, H & Lundgaard, K. L. 2005, ApJ 632, L41.

- Boss, A. P., 1995, *ApJ* 439, 224.
- Brown, A. G. A., de Geuss, E. J. & de Zeeuw, P. T., 1994, *A&A* 289, 101.
- Cameron, A. G. W., Hoefflich, P., Myers, P. C., & Clayton, D. D., 1995, *ApJ*, 447, L53.
- Carpenter, J. M. 2000 *AJ*, 120, 3139.
- Chevalier, R. A., 2000 *ApJ*, 538, L151.
- Churchwell, E. B., Felli, M., Wood, D. O. S. & Massi, M. 1987, *ApJ*, 321, 515
- Clayton R. N., Grossman, L., & Mayeda, T. K. 1973, *Science*, 182, 485.
- Ellinger et al., in prep.
- Elmegreen, B. G. & Lada, C. J. 1977, *ApJ* 214, 725.
- Gaidos, E. J., 1995, *Icarus* 114, 258.
- Gladman, Chan 2006, *ApJ* 643, L135.
- Gutermuth, R. A., Megeath, S. T., Pipher, et al. 2005 *ApJ* 632, 397.
- Gutermuth, R. A., Pipher, J. L., Megeath, S. T. et al., 2007, in prep.
- Hahn, J. M. & Malhotra, R., 2005, *AJ* 130, 2392.
- Hevey, P. J. & Sanders, I. S. 2006, *Meteoritics & Planetary Science*, 41, 95.
- Heyer, M. H., Terebey, S., 1998, *ApJ* 502, 265.
- Hernandez, J., Hartmann, L., Megeath, T. 2007 *ApJ* in press.
- Hester, J. J. & Desch, S. J. 2005, in *ASP Conf. Ser. 341: Chondrules and the Protoplanetary Disk* ed. Krot, Scott, & Reipurth, 527.
- Hester, J. J., Desch, S. J., Healy, K. R., Leshin, L. A. 2004, *Science* 304, 1116.
- Hester, J. J., Scowen, P. A., Sankrit, R. et al., 1996, *AJ*, 111, 2349.
- Hoogerwerf, R., de Bruijne, J. H. J. & P. T. de Zeeuw, 2001, *A&A* 365, 49.
- Kastner, J. H. & Myers, P. C., 1994, *ApJ* 421, 605.
- Kenyon, S. J. & Bromley, B. C., 2004, *Nature* 432, 598.
- Lada, C. J. & Lada, E. A., 2003 *ARA&A* 41, 57.
- Lee, J.-E., Bergin, E. & Lyons, J. submitted to *Meteoritics & Planetary Science*
- Levison, H. F. & Morbidelli, A., *Nature* 2003, 426, 419.
- Looney, L. W., Tobin, J. J., Fields, B. D. 2006, *ApJ* 652, 1755.
- Megeath, S. T., Wilson, T. L. *AJ*, 2007, *AJ* 114, 1106.
- Megeath, S. T., Allen, L. E., Gutermuth, R. A. et al., 2004, *ApJS*, 154, 367.
- Megeath, S. T., Gutermuth, R. A., Hora, J. L., et al., 2007, in prep.
- Melioli, C., De Gouveia Dal Pino, E. M., et al., 2006, *MNRAS*, 373, 811.
- McCaughrean, M. J., Andersen, M., 2002, *A&A* 389, 513.
- Morbidelli, A. & Levison, H. F., 2004, *AJ* 128, 2564.
- Moriarty-Schieven, G. H., Johnston, D., Bally, J. & Jenness, T., 2006, *ApJ* 645, 357.
- O'dell, C. R. & Zhen, W., 1994, *ApJ*, 436, 194.
- Ouellette, N., Desch, S. J., Hester, J. J., Leshin, L. A., 2005, in *ASP Conf. Ser. 341: Chondrules and the Protoplanetary Disk* ed. Krot, Scott, & Reipurth, 527.
- Porras, A., Micol, C., Allen, L., et al., 2003, *AJ* 126, 1916.
- Reach, W., Rho, J., Young, E., et al., 2004, *ApJS* 154, 385.
- Sekiya, M., 1998, *Icarus* 133, 298.
- Sherry, W. H., Wlaler, F. M. & Wolk, S. J. 2004, *AJ* 128, 2316.
- Sicilia-Aguilar, A., Hartmann, L., Calvet, N. et al., 2006, *ApJ* 638, 897.
- Schertl, D., Balega, Y. Y., Preibisch, Th. & Weigelt, G., 2003, *A&A* 402, 267.
- Sugitani, Motohide, T., Ogura, K., 1995, *ApJ* 455, L39.
- Tachibana, S. & Huss, G. R., 2003. *ApJ*, 588, L41.
- Thrane, K., Bizzarro, M. & Baker, J. A. 2006 *ApJ* 646, L159.
- Throop, H. B., Bally, J., 2005, *ApJ* 623, L149.
- Throop, H. B., Bally, J. 2007 in prep.
- Townsley, L. K. 2006 to appear in "Massive Stars: From Pop III and GRBs to the Milky Way", ed. M. Livio (astro-ph/0608173).
- Tremaine, S., 1991, *Icarus*, 89, 85.
- Vanhala, H, A. T. & Boss, A. P. 2002, *ApJ* 576, 1144.
- Williams, J. P., & Gaidos, E. J. in prep.
- Wolk, S. J., Bourke, T. L., Smith, R. K., et al., 2002 *ApJ* 580, L161.

Youdin, A. N. & Shu, F. H., 2002, ApJ 580, 494.